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FEBRUARY 1941

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PULMONARY DISEASES IN THE MINING INDUSTRY

BY

R. R. SAYERS

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February 1941.

INFORMATION CIRCULAR

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

PULMONARY DISEASES IN THE MINING INDUSTRY[1]

By R. R. Sayers[2]

Although the attention of those interested in diseases peculiar to mining has been focused recently on one dust disease - silicosis - other respiratory diseases may cause more suffering and economic loss. The increased incidence of these diseases usually is attributed to exposure to abnormal air conditions underground, such as sudden changes from high to low temperatures, excessive dust, and noxious gases. The principal respiratory diseases to which the miner is subject are bronchitis, influenza and pneumonia, pulmonary tuberculosis, anthracosilicosis, and silicosis. Although the mortality statistics in some of the tables included in this paper are old they have been corroborated by later, less complete data.

Bronchitis

Bronchitis is an inflammation of the bronchial tubes due, among other causes, to the inhalation of irritants such as dusts (organic and inorganic). Occupations that entail exposure to atmospheres polluted by irritating gases carry with them the risk of bronchitis. According to Collis (1), it cannot be distinguished clinically from bronchitis occurring among the general population, and its association with the inhalation of dust or gases usually is unrecognized.

During middle life bronchitis causes much recurrent invalidity and incapacity. Mortality records compiled by Collis (2) indicate that it is of a chronic traumatic origin associated with irritating atmospheric conditions, rather than of an infectious origin.

Statistics for bronchitis for the general population and for workers exposed to dusts in Great Britain (3) for 1921-23 show the role played by dusts in the increased incidence of the disease in certain industries. The comparative mortality per thousand (ages 20 to 65) for those in occupations exposed to siliceous dust was 214, for those exposed to nonsiliceous dust 59.5, and for the general population 49.6. (See table 1.)

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Presented before the Mining Section, 29th National Safety Congress and Exposition, Chicago, Ill., Oct. 9, 1940.

2/ Director, Bureau of Mines, senior surgeon, U. S. Public Health Service.

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TABLE 1. - Mortality per 1,000 from bronchitis in dusty occupations and in the general population, by age groups

	Ages at death					Comparative Mortality figure
	20-	25-	35-	45-	55-	20-65
Occupations exposed to:						
Siliceous dust...	1.1	1.0	13.7	44.6	153.7	214.0
Nonsiliceous dust	-	-	4.9	12.8	41.8	59.5
General population.	0.5	1.7	5.4	13.3	28.8	49.6

In this connection it is interesting to note the mortality statistics per thousand (ages 20 to 65) for coal miners of counties of Wales (in which most of the coal mined is anthracite) compared with those for two other groups in England and Wales (4). The figures for coal miners are 112 for all underground workers and 139 for hewers and getters, compared with 46 for males in the same social class and 50 for all occupied and retired males. (See table 2.)

TABLE 2. - Comparative mortality figures for bronchitis per 1,000 of certain groups in England and Wales

Coal miners 1/:	Bronchitis (ages 20-65)
All underground workers.....	112
Hewers and getters.....	139
Males in same social class....	46
All occupied and retired males	50
Ratio of rate for hewers and getters to rate for same social class.....	302

1/ In 3 counties in Wales.

In a study by the United States Public Health Service (5) 35 cases of chronic bronchitis were found among 344 employees of two anthracite-mining companies examined.

In the study conducted by the Bureau of Mines and the Public Health Service at Picher, Okla. (6), the highest incidence of silicosis or tuberculosis, or both, was found among men who reported having had bronchitis, pleurisy, and asthma.

Influenza and Pneumonia

Figures of mortality available for 4,700 miners insured in the group department of the Metropolitan Life Insurance Co. (7) show that in the last quarter of 1918 during the influenza epidemic 64 of these miners died of influenza or pneumonia. This is equivalent to an annual death rate of 50 per 1,000. Among all occupied males aged 15 years and over the rate from

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influenza-pneumonia in the same 3 months was 22 per 1,000, or less than half as high. In the age period 45 to 65 years the rate among bituminous-coal miners was about four times as high as among all occupied males in the same age group. (See table 3.)

TABLE 3. - Influenza-pneumonia mortality among bituminous-coal miners, October to December 1918

Age period	Annual death rate per 1,000	
	Bituminous-coal miners	All industrial white males
All ages[1]	50.1	22.3
15-25	29.5	17.5
25-45	62.1	32.6
45-65	44.4	11.7

1/ 15 years and over.

Influenza and pneumonia, as reported, were responsible, in the years under study, for 31 percent of the mortality in the group of bituminous-coal miners at ages 16 to 70 in Indiana, Missouri, and Wyoming, compared with 19 percent among both farmers and "all other males" at these ages in the same counties. (See table 4.)

TABLE 4. - Percentage of deaths from influenza and pneumonia (after deducting accidents) among bituminous-coal miners compared with farmers, and with other males in the same areas of several soft-coal-producing States[1]

Male groups under comparison	Ages					
	16-70	16-30	31-40	41-50	51-60	61-70
Bituminous-coal miners....	31.1	49.4	44.7	25.1	19.7	10.4
Farmers.....	18.7	38.4	32.4	19.7	12.4	10.8
All other males.....	18.6	30.0	29.0	16.0	11.3	10.8

1/ The death records for soft-coal miners were obtained from 15 coal-producing counties of Indiana, 1916-20, inclusive, 8 coal counties of Missouri, 1917-21, inclusive, and the 6 principal coal-producing counties of Wyoming, 1919-23, inclusive. The record for farmers and for "all other males" was obtained from the above-mentioned coal-mining counties and also from 3 agricultural counties of Wyoming, 1919-23.

In 1918, the year of the great epidemic, influenza and pneumonia deaths constituted 55 percent of total mortality exclusive of accidents among the bituminous miners, in contrast with 27 percent among the farmers and 34 percent among all other males. These percentages were not as high as the figures for Wilkes-Barre. The fact that the soft-coal counties under consideration are largely rural areas may have made some difference.

In the epidemic year 1920 the proportion of deaths from influenza and pneumonia was smaller than in 1918, but, as was found for the anthracite miners, the bituminous group showed a wider difference in the proportion

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of deaths from this cause compared with "all other males" than in 1918. The percentages in 1920 were 29 for the soft-coal miners and 16 for "all other males." In this epidemic the bituminous miners at ages 40 to 60 suffered heavy excess mortality from influenza-pneumonia, but the differential mortality was not quite so great as at ages 16 to 30.

Among hewers and getters of soft coal in England and Wales, the death rate from influenza and pneumonia, 1921-23, was about 12 percent greater than among males of comparable social status (social class 3). The difference was found to be 5.8 times the probable error of the difference, which is certainly a significant variation. Thus, an abnormal mortality from influenza and pneumonia is consistently indicated among miners of coal, both anthracite and bituminous, in England as well as in America.

The pneumonia-mortality figures in 1921-23 for occupations in Great Britain exposed to siliceous and nonsiliceous dust compared with those for the general population were given by Collis (1) as 134.3, 76.0, and 85.3, respectively; similar figures for influenza were 47.1, 49.6, and 36.5, respectively. (See table 5.)

TABLE 5. - Mortality per 1,000 from pneumonia and influenza in dusty occupations and in the general population

	Pneumonia					
	Ages at death					Comparative mortality figure
	20-	25-	35-	45-	55-	20-65
Occupations exposed to:						
Siliceous dust.....	3.3	14.4	30.6	47.2	38.7	134.3
Nonsiliceous dust.....	-	9.6	13.7	28.7	23.9	76.0
General population....	4.3	11.5	19.6	24.2	25.7	85.3
	Influenza					
Occupation exposed to:						
Siliceous dust.....	1.1	7.7	11.3	8.7	18.3	47.1
Nonsiliceous dust.....	5.4	4.8	13.7	10.6	14.9	49.6
General population.....	2.0	5.2	7.7	9.7	12.0	36.5

According to Brundage (4), an outstanding feature of the statistics of death for hard-coal miners in the United States is their extraordinary mortality from influenza and pneumonia not only during influenza epidemics but at other times as well. In a study by the Public Health Service at Wilkes-Barre, Pa., in 1915-23 and 1906-25 (4) it was found that influenza and pneumonia were responsible for 40 percent of the total deaths, compared with 25 percent among males at ages 15 to 65 who had been engaged in pursuits other than coal mining in Wilkes-Barre and vicinity. The percentage of deaths from influenza and pneumonia for these two groups, by ages, for the years mentioned was 19.3 for anthracite miners compared with 13.3 for males in other industries. (See table 6.)

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TABLE 6. - Percentage of deaths from influenza and pneumonia among anthracite miners and among males in occupations other than mining in Wilkes-Barre and vicinity

Groups under comparison	Ages					
	15-64	15-24	25-34	35-44	45-54	55-64
Anthracite miners.	39.8	45.2	67.9	42.9	31.8	19.3
Males in other industries.....	25.3	28.7	46.2	31.0	16.8	13.3

Tuberculosis

In 1925 Collis (8) said that for coal miners generally the tuberculosis rate apparently is low, although miners at the coal face suffer from the disease more than other coal miners underground and workers above ground. Results of more recent investigations seem to contradict the assumption that tuberculosis does not occur among coal miners. An investigation by the Welsh School of Medicine, reported in 1937 (9), indicates that this supposed exemption of coal miners from tuberculosis may be due to a mis- or partial diagnosis. This investigation revealed a high incidence of tuberculosis (35 percent if the "probable" cases are included) among the pneumoconiotics of the South Wales coal fields and supports the theory that coal dust modifies the tuberculosis, leading to failure to recognize the disease or to the mistaken diagnosis of "bronchitis."

Studies by the United States Public Health Service (10) revealed that 6 percent of hard-coal miners examined had clinical pulmonary tuberculosis. The average prevalence in the adult male population of the United States is about 2 percent. The prevalence of pulmonary tuberculosis among hard-coal mining employees at ages below 35 was slightly less than that found through studies among male adults in the general population. In the age group 35 to 44, however, the prevalence of tuberculosis was about twice, at ages 45 to 54 about 5 times, and for ages above 55 it was about 10 times the rate found in the general population. The highest prevalence of clinical pulmonary tuberculosis occurred among the rock workers (men who had been employed in rock loading or rock extraction for more than 2 or 3 years). After 20 years' service, of which more than 2 or 3 years were in rock work, 37 percent presented evidence of pulmonary tuberculosis. In a group of 135 completely disabled former anthracite workers, which did not include any known cases of tuberculosis, 10 percent proved positive for pulmonary tuberculosis. These findings would appear to corroborate those of the Welsh National School of Medicine that indicate that the supposed exemption from tuberculosis of coal miners is erroneous owing to incorrect diagnosis. There is evidence that the above increased incidence of tuberculosis is associated with exposure to silica dust.

The incidence of tuberculosis is much higher in metal mines than in coal mines, owing no doubt to exposure to dust containing a higher concentration of silica. An investigation in 1914 by the Bureau of Mines in cooperation with the Public Health Service of pulmonary disease among the

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zinc miners of the Joplin, Mo., district, revealed a high death rate from pulmonary tuberculosis. The mortality rate for tuberculosis for Jasper County was 200.8 per 100,000 for 1911 and 1912 and 229.7 for 1913, according to statistics of the State Board of Health (11). On the other hand, according to the Jasper County Antituberculosis Society, during the calendar year 1912 there were 720 deaths among miners who had worked 2 years or more underground in Jasper County. Not all of these 720 deaths occurred in that county, but they had contracted the disease there and some of them had moved away. Of 93 miners in the Joplin District examined by Lanza in 1914 (11), 64 showed definite symptoms of pulmonary disease and 39 of the 64 had the classical symptoms of pulmonary tuberculosis.

In a study by the Bureau of Mines and the Public Health Service (12) in Butte, Mont., during 1916 to 1920 the death records of the State Board of Health were examined. These showed that during 1915, 122, during 1916, 126, and during 1917, 169 Butte miners died of tuberculosis. The significance of the death from tuberculosis of 169 miners in 1917 is indicated by comparison with the record of other regions. In 1917 approximately 14,000 men were employed underground in Butte mines; with 169 deaths from tuberculosis for the year, the rate per 100,000 was 1,207. The tuberculosis death rate of Michigan for the 10-year period 1910 to 1920 was 97.4 per 100,000; hence the tuberculosis death rate of Butte miners was nearly 13 times as great as that of Michigan.

The part played by dust, especially dust containing silica, in the production of pulmonary tuberculosis is shown clearly by figures for Great Britain for 1921-23 (3). The death rate per 1,000 for ages 20 to 65 was 592.2 for those exposed to siliceous dust, 172.4 for those exposed to nonsiliceous dust, and 163.5 for the general population; for ages 35 to 44 the figures were 141.0, 46.1, and 43.6, respectively; for ages 45-54 the figures were 211.6, 56.4, and 39.0, respectively; and for ages 55 and over the figures were 150.6, 29.9. and 22.7, respectively. (See Table 7.)

TABLE 7. - Mortality per 1,000 from pulmonary tuberculosis in dusty occupations and in the general population

	Ages at death					
	20-	25-	35-	45-	55-	20-65
Occupations exposed to:						
Siliceous dust.....	25.6	63.4	141.0	211.6	150.6	592.2
Nonsiliceous dust..	13.6	26.3	46.1	56.4	29.9	172.4
General population...	20.6	37.6	43.6	39.0	22.7	163.5

According to Collis (2) the prevalence of bronchitis, pneumonia, and tuberculosis is high among those exposed to silica dust, but the incidence of these diseases is not always the same under other conditions such as exposure to other dusts, heat, and fumes, or working indoors. (See table 8.)

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TABLE 8. - Prevalence of bronchitis, pneumonia, and tuberculosis under certain conditions of exposure

Exposure	Bronchitis	Pneumonia	Tuberculosis
Outdoor and indoor life.....	Low	Low	Low
Indoor industries.....	do.	do.	High
Coal trade.....	High	High	Low
Alcohol trade.....	Moderate	do.	High
Heat and fumes.....	High	do.	Low
Dust of:			
1. Animal origin.....	Low	Low	do.
2. Vegetable husks and debris, certain inorganic materials.....	High	Medium	do.
3. Silica.....	do.	High	High

Anthracosilicosis

From 1931 to 1937, 87 percent of the total deaths in Great Britain due to silicosis occurred among the coal miners of South Wales; two thirds of the deaths and disease occurred in the Swansea Division; and 89 percent of the medical certificates granted in the Swansea Division related to anthracite collieries (13).

In the United States the chronic disease among miners due to breathing air containing dust generated in the various processes involved in the mining and preparation of anthracite is called anthracosilicosis. This is a descriptive title for the form of pneumoconiosis commonly called miners' asthma. The disease was found in about 23 percent of 2,711 employees of three anthracite mining companies studied by the United States Public Health Service in 1933. About 63 percent of those having anthracosilicosis showed evidence of disability, compared with less than 10 percent in the control group. Moderate and marked degrees of disability handicapped approximately 21 percent of those with anthracosilicosis compared with less than 2 percent of the men serving as controls.

Wide differences were found in the extent of physical impairment in the several occupational groups. The highest rate of disability from all causes combined was found in the group of men that had changed more than 5 years before the date of examination from very dusty to relatively nondusty occupations in the industry. In a number of instances the change in occupation probably was made on account of physical condition. Miners at the coal face, rock workers, and men who had had appreciable exposure to harmful dusts in other industries also showed evidence of much greater physical impairment than was found in the control group.

Moderate or marked physical impairment from any cause was found in 1.7 percent of the control group, in 9.9 percent of the regular miners, and among 12.6 percent of the rock workers.

There was a marked tendency toward increase in the proportion having physical impairments with increase in the number of years of employment in anthracite. This tendency is manifested whether one considers disability

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of any kind, disability in which pulmonary infection was contributory, or disability due largely to tuberculosis. In each case the occupational groups arrayed themselves according to extent of physical impairment, as follows: (1) Rock workers; (2) regular miners; (3) all others exposed to more than 100 million dust particles per cubic foot of air; and (4) men in haulageways, except rock workers.

The pathology of anthracosilicosis as observed in these cases is essentially a deposition of coal dust in the lungs accompanied by an extensive fibrosis, both diffuse and nodular, with associated functional and degenerative changes. (Silicosis modified by coal dust.)

That excess mortality from respiratory diseases as a whole is experienced by American hard-coal miners is clear from the studies made by the Public Health Service (4). The anthracite miners' proportionate mortality from all respiratory diseases was about 1-1/2 times that of the other adult males in the same region. When proportionate mortality was computed for ages 16 to 65 in Wales (4) it was found that respiratory diseases accounted for 53 percent of the deaths of anthracite miners, compared with 38.2 percent among males in the same social class. The proportion among hewers and getters of anthracite therefore was 1.4 times that of men of the same social status.

Silicosis

There are various definitions of silicosis, but all agree that the cause of the disease is the inhalation of silica or quartz dust (14). Silicosis is a well-recognized clinical and pathological entity at least as characteristic as any cause of death known to epidemiologists (15). The definition of silicosis adopted at the International Silicosis Conference in 1930 and reaffirmed at the 1939 Conference and generally accepted is:

> Silicosis is a pathological condition of the lungs due to inhalation of silicon dioxide. It can be produced experimentally in animals.

The first investigation of silicosis in the mining industry in the United States was made in 1914-15 by the Federal Bureau of Mines in cooperation with the United States Public Health Service in the Joplin (Mo.) mining district (11). As only a few men were examined at that time, it was decided to examine a larger number to gain a more accurate idea of the prevalence of consumption among the miners of this district. From May 15 to December 31, 1915, 720 miners were examined: 45.7 percent had silicosis and tuberculosis and 5.3 percent had tuberculosis (16). A later report (1917) of this same investigation by Lanza and Childs (17) included the results of the first detailed X-ray studies of silicosis made in the United States.

Investigations of mining conditions by Harrington and Lanza (12) in Butte, Mont., in 1921, revealed that 42.4 percent of 1,018 miners examined showed definite signs of lung damage due to dust.

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From July 1, 1927, to June 30, 1932, the Metropolitan Life Insurance Co., the Tri-State Zinc & Lead Ore Producers Association, and the Federal Bureau of Mines operated a cooperative clinic at Picher, Okla., (18) to demonstrate to industry a workable method for diagnosis of silicosis, to educate workers in preventive measures, and to serve as a model to industries presenting a dust hazard. Of 27,553 individuals examined during this period 5,366 had silicosis, 742 silicosis plus tuberculosis, and 320 uncomplicated tuberculosis.

The chief cause of disability in silicosis is tubercle infection. The silicotic lung appears to be a more favorable medium for the growth of the tubercle bacillus than the normal lung, not because it is fibrotic nor because its lymphatic drainage is interfered with but because it contains silica (19). Apparently silica dust possesses this characteristic of increasing the liability to pulmonary tuberculosis. That this is true is indicated by the statistics quoted in this paper which indicate also that silica dust increases the liability to other respiratory diseases. (See table 9.)

TABLE 9. - Mortality from certain respiratory diseases of those exposed to siliceous dust, to nonsiliceous dust, and the general population - by age groups 1/

Groups	Respiratory diseases											
	Bronchitis						Influenza					
	20-	25-	35-	45-	55-	20-65	20-	25-	35-	45-	55-	20-65
Siliceous dust.	1.1	1.0	13.7	44.6	153.7	214.0	1.1	7.7	11.3	8.7	18.3	47.1
Nonsiliceous dust.....	-	-	4.9	12.8	41.8	59.5	5.4	4.8	13.7	10.6	14.9	49.6
General population.....	0.5	1.7	5.4	13.3	28.8	49.6	2.0	5.2	7.7	9.7	12.0	36.5
	Pneumonia						Tuberculosis					
	20-	25-	35-	45-	55-	20-65	20-	25-	35-	45-	55-	20-65
Siliceous dust.	3.3	14.4	30.6	47.2	38.7	134.3	25.6	63.4	141.0	211.6	150.6	592.2
Nonsiliceous dust.....	-	9.6	13.7	28.7	23.9	76.0	13.6	26.3	46.1	56.4	29.9	172.4
General population.....	4.3	11.5	19.6	24.2	25.7	85.3	20.6	37.6	43.6	39.0	22.7	163.5

1/ Made up from tables 1, 5, and 7.

The results of virtually all studies are in agreement regarding the high mortality from tuberculosis for industries in which large numbers of men are exposed to a silica hazard. These rates are so high that they leave no room for doubt of the cause-and-effect relationship between the hazard and the high mortality (20).

Joint studies made by the Actuarial Society of America and the Association of Life Insurance Medical Directors (20) revealed that there were 65 deaths where 6 were expected (about 11 times the expected number) from tuberculosis in 1925-1936 among a group of underground miners, most of whom

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were employed in metal mines. Tuberculosis deaths were fourteen times the expected among copper miners, nine times the expected among gold and silver miners, and eight and a half times the expected among iron miners. In an earlier study (20) covering the years 1915-1926 there were 18 times as many deaths as expected among lead and zinc miners.

An analysis by the field division of the Saranac Laboratory (21) of the roentgenograms of 5,000 white miners exposed to the inhalation of harmful concentration of silica dust shows that the incidence of pulmonary tuberculosis lesions increases as the degree of reaction to dust progresses. In this group of miners tuberculosis lesions were found in approximately one fourth of those with first-stage silicosis, one half of those in the second stage, and 65 percent of those in the third stage (21).

PREVENTION OF DUST DISEASES IN MINING

The data given in this paper point to dust as the greatest contributor to the excessive mortality from pulmonary diseases experienced in the mining industry and to silica dust as the immediate cause of the disease silicosis. Therefore, the principal method of preventing these diseases is to eliminate as far as possible or reduce to harmless concentration the dust in the breathing zone of the workers. Experience has shown that the properties of a dust that determine its capacity to produce injurious effects are its composition, the quantity suspended in the atmosphere breathed by the worker, and its particle size.

Although any dust may be harmful to breathe under certain conditions, as indicated by the data presented here that show a higher incidence of pulmonary diseases in nonsiliceous dusty industries than in the general population, physiological studies reveal that, in general, the harmfulness of a dust is proportional to its content of free silica or quartz, in particles small enough to enter the finer air spaces of the lungs, and in high enough concentration to overcome the normal defenses of the respiratory system.

The prevention of dust diseases is the function of the physician and the engineer, working together to determine the extent of the dust hazard in industry and methods for its control.

The first step is to determine what dusts are harmful and in what concentrations. The procedure is somewhat as follows: It is observed that respiratory diseases appear more frequently or with greater severity among workers in certain industries or in connection with certain operations within an industry. The physician attempts to determine the extent of the injury to the health of those exposed and the cause. If the cause appears to be exposure to excessive dust, the engineer samples the air to determine the kind, amount, and size of the dust present. The physician and the engineer can correlate the results of their investigations to determine allowable concentrations of dust, exposure to which is not likely to cause harmful physiological reactions. The engineer is then in a position to devise measures for the reduction of the dust to a harmless concentration. The aim, of course, should be to eliminate the dust entirely or to reduce the dust to a concentration that will not cause disability during the working lifetime.

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Investigations conducted over a period of years show that exposure to certain concentrations of harmful dusts for a certain time cause varying degrees of respiratory disability, but that below these concentrations disabling pulmonary diseases do not occur within a working lifetime. The classical example of this is the experience in South Africa with the reduction in mortality from silicosis that has followed the reduction in air dustiness in the mines of that country.

The reduction in the incidence of silicosis in the South African mines attests the effectiveness of the control measures employed and the practicability of using a definite dust concentration as a guide in setting allowable limits of air dustiness in the prevention of pneumoconiosis in dusty industries. The production rate of silicosis in the scheduled mines of South Africa (22) in 1932-35 was 9.59 per 1,000, compared with 21.95 in 1917-18. (See table 10.)

TABLE 10. - Average number of miners examined annually and production rates for silicosis in each triennial period since 1917-18

Period	Average number of miners examined annually	Production rate of silicosis per 1,000	Period	Average number of miners examined annually	Production rate of silicosis per 1,000
1917-20	14,070	21.95	1926-29	14,624	21.11
1920-23	13,260	19.16	1929-32	16,774	13.87
1923-26	12,523	33.28	1932-35	20,139	9.59

The incidence rates for silicosis uncomplicated by active tuberculosis among South African miners in 1936-37 was between 8 and 9 per 1,000 per annum (23). The liability among the whole body of miners to contract the disease in 1936-37 was less by 65 percent than it was in 1920-23. Among the "new Rand miners" who entered the industry by way of initial examination since 1916 and who have been exposed solely to the progressively improving occupational conditions that have obtained since that date, the liability to contract silicosis was less by 87 percent than the similar liability among all miners working for an equal period in 1920-23. These "new Rand miners" constituted 77 percent of all working miners examined. The group of pre-1916 miners who in 1935-36 constituted less than 17 percent of the total number of working miners contributed nearly 78 percent of the new cases of silicosis.

In the study by the Public Health Service (10) of anthracosilicosis among hard-coal miners silicosis was not found in a control group of mining employees whose dust exposure averaged less than 5 million particles per cubic foot of air.

The prevalence of anthracosilicosis among the entire group of employees was found to be about 23 percent.

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Among all except rock workers less than 2 percent of the men developed anthracosilicosis when the duration of employment was less than 15 years regardless of the amount of dust in the air.

Among men exposed 15 to 24 years to dust containing less than 5 percent free silica 14 percent of those who had worked where the average dust count was 100 to 199 million particles per cubic foot, 29 percent of those exposed to 200 to 299 million particles, and 58 percent of the men who had worked for this period in more than 300 million particles per cubic foot developed anthracosilicosis.

Among men employed for more than 25 years in dust containing less than 5 percent free silica the proportion of persons found with anthracosilicosis under different concentrations of dust was as follows: 5 to 99 million particles, 7 percent; 100 to 199 million particles, 54 percent; 200 to 299 million particles, 71 percent; 300 or more million particles per cubic foot, 89 percent.

With the exception of miners, their helpers, and rock workers, about 25 percent of all the men employed underground developed anthracosilicosis after a working period of more than 25 years. This group was exposed to dust having a quartz content of about 13 percent.

The prevalence of anthracosilicosis among persons who had been exposed for more than 2 or 3 years to dust of which about 35 percent was free silica ranged from 10 percent among those who had worked in concentrations of less than 200 million particles per cubic foot for less than 15 years to 92 percent among those who had been employed for more than 25 years in dust concentrations exceeding 300 million particles per cubic foot, more than 2 or 3 years of which time was spent in rock work.

Age per se appeared to play a minor role in the development of anthracosilicosis.

Analysis of the data for the purpose of determining safe limits of dust exposure indicated that employment in an atmosphere containing less than 50 million dust particles per cubic foot would produce a negligible number of cases of anthracosilicosis when the quartz content of the dust was less than 5 percent. In the gangways where the silica content of the dust was about 13 percent, a safe limit appeared to be 10 to 15 million particles per cubic foot. The limit of toleration for rock workers was set tentatively at 5 to 10 million particles per cubic foot of air. Similar results were obtained by the Public Health Service in an investigation of pneumoconiosis among mica and pegmatite workers. (See table 11.)

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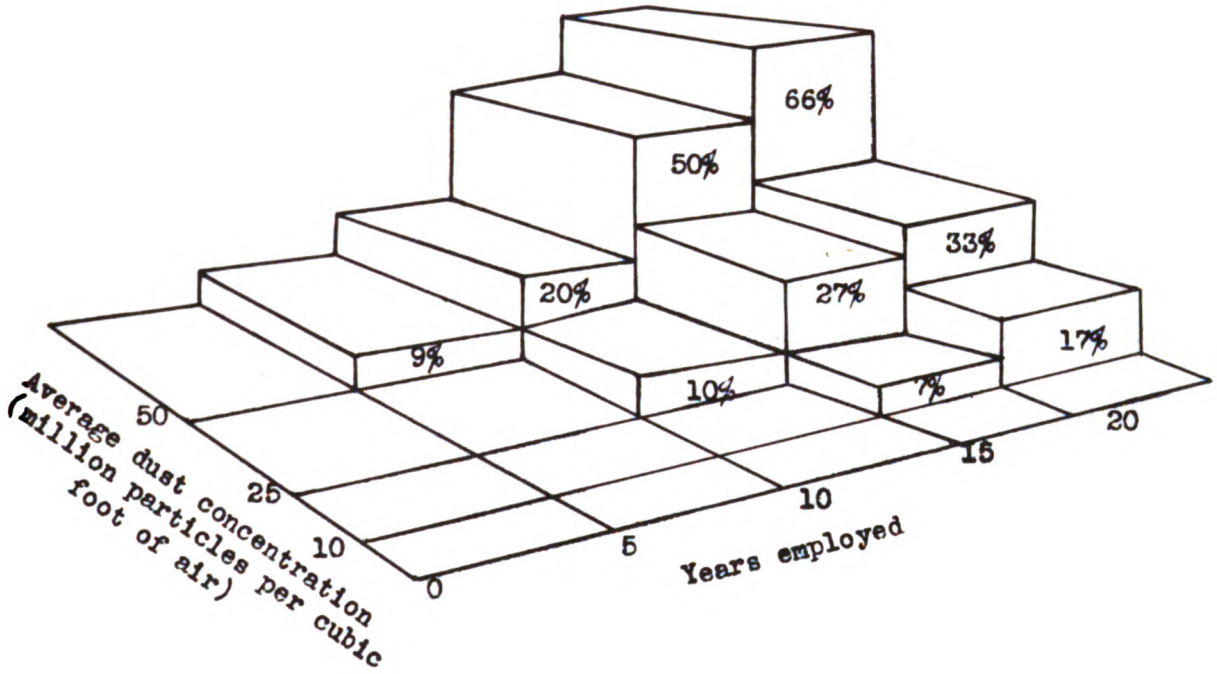

Figure 1. - Relation of average dust concentration and duration of dust exposure to the percentage of workers found to have pneumoconiosis. (Based on data presented in table 11.)

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TABLE 11. - Pneumoconiosis cases occurring among 798 workers exposed to mixed dust, classified by average dust concentration, length of employment, and number of workers exposed

Average dust concentration (million particles per cubic foot)	Years in industry				
	0-4.9	5-9.9	10-14.9	15-19.9	20 and over
0-9:					
Pneumoconiosis cases...number	0	0	0	0	0
Workers exposed..... do.	81	56	29	13	8
Workers with pneumoconiosis.....percent	0	0	0	0	0
10-24:					
Pneumoconiosis cases..number	0	0	0	2	4
Workers exposed..... do.	123	94	66	29	23
Workers with pneumoconiosis.....percent	0	0	0	6.9	17.4
25-49:					
Pneumoconiosis cases...number	0	0	3	3	6
Workers exposed..... do.	43	45	31	11	18
Workers with pneumoconiosis.....percent	0	0	9.7	27.3	33.3
50 and over:					
Pneumoconiosis cases...number	0	4	5	4	4
Workers exposed..... do.	45	44	25	8	6
Workers with pneumoconiosis.....percent	0	9.1	20.0	50.0	66.7

The relation of the average dust concentration and duration of exposure to the percentage of workers found to have pneumoconiosis was as follows: Of those who had worked in an average concentration of 50 million particles of dust per cubic foot of air, 9 percent had pneumoconiosis in 5 years, 20 percent in 10 years, 50 percent in 15 years, and 66 percent in 20 years. Of those who worked in an average concentration of 25 million particles 10 percent had pneumoconiosis in 10 years, 27 percent in 15 years, and 33 percent in 20 years. Of those who had worked in an average concentration of 10 million particles, 7 percent had pneumoconiosis in 15 years, and 17 percent in 20 years. (See fig. 1.)

The data obtained in other studies of dusty trades, anthracite mining, asbestos textile manufacture, and the pottery industry have been treated in a similar fashion and have yielded similar although usually less regular results. The position of the threshold value below which no cases were found and the magnitude of the trends between percentage affected and both time and intensity of exposure varies in different sets of data, depending to a large extent on the chemical nature of the dust to which workers were exposed and possibly on the regularity of employment.

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It is tempting to seek to summarize the data of table 11 and figure 1 into a simple mathematical relation such as the following: With each two-fold increase in average dust concentration above 10 million particles per cubic foot the probability of finding cases of silicosis (in men exposed for comparable lengths of time) is approximately doubled. Application of the standard methods of curve-fitting would yield more refined descriptions of these data. Nevertheless, it does not seem to be advisable to set up any mathematical treatment, because of all the men who entered the industry only the survivors have been studied. There is no adequate way of determining whether or not men who dropped out of the industry were in a better or worse state of health as far as silicosis is concerned than men who remained in the industry, and thus there is no way of introducing a correction for this element of selection into a mathematical treatment. It seems to be preferable to present the facts as simply as possible, together with the precautions to be kept in mind in studying them, and to emphasize that the principal use of these data is to show the degree of improvement in health to be expected in the future if dust formation and dust dispersal are brought under control in these and in similar industries.

Methods of Dust Control

Determination of the Dust Hazard

After the physician and engineer have learned by observation and experimentation what kinds of dust are harmful and in what concentrations, it is the function of the engineer to evaluate the hazard in a particular industry, plant, or mine and devise measures for its elimination. The first step is to become thoroughly familiar with the industry being studied to determine the dusty occupations, the number of persons in each, and the various activities and time devoted to each activity in any one occupation (24).

The amount of harmful dust created by various activities can be determined by taking samples of the atmosphere in their vicinity and counting and identifying the dust particles. Sampling of air is also a means of checking the efficiency of any control measures that may be adopted.

Several devices are available for collecting and counting dust samples. The impinger, however, is the instrument used most frequently in the United States. The Bureau of Mines and the Public Health Service have issued publications describing the method of sampling dust by the impinger (as well as by other methods) and procedures for counting and identifying the particles (24 and 25).

Dust sampling is complicated by the fact that air dustiness fluctuates rapidly from moment to moment. A single dust count represents only the amount of dust in the atmosphere at the time and place of sampling and gives no indication of the average exposure of the worker over a period of years, especially if he has not worked continuously at one job. The ultimate lung injury that he may suffer will depend upon the integrated effect of the dust over a long period (26). A proper measure of dust exposure requires a picture of the variations in dustiness. The best procedure

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is to determine the dustiness during different stages of an operation and, with the aid of a time study, to break down the worker's day according to the time spent in each step; from these data the average dust exposure of the worker can be calculated.

Drilling. - Experience in South Africa (27) with new methods of sampling have revealed that more dust is produced by rock drills than had been suspected, the difference consisting entirely of dust too fine to be detected by the older methods. The importance of control of drilling dust as a measure of the prevention of silicosis is demonstrated by the fact that the incidence of silicosis has remained consistently and considerably higher among machine drillers than among those who have never worked machines, and the excess incidence among machine drillers has been in direct proportion to the amount of time spent on rock drilling.

Until relatively recently drilling of holes for blasting was a negligible producer of dust or air dustiness in coal mines especially other than anthracite mines. The hand-operated auger drill produces very little fine dust, but with the extension of mechanized mining power drills are becoming more and more essential, and some of them are heavy producers of finely divided dust; this is especially true of reciprocating drills of the jackhammer type drilling dry and using compressed air in the drilling of holes either in coal or in roof or floor material.

Blasting. - The exceptionally heavy incidence of silicosis among rock-drill miners in the early period of the gold-mining industry in South Africa (28) was due to the exposure of the rock-drill miner not only to drilling dust but to high concentrations of dust from blasting, and frequently to the inhalation of varying amounts of the irritant fumes produced by blasting, owing to the methods of blasting then in use. Blasting produces large quantities of very fine dust, the finest fractions of which tend to remain suspended in the mine air for a long time, unless removed by ventilation.

Shoveling or mucking. - In the Picher, Okla., study (6) it was difficult to show the relationship of the duties of the men to silicosis because of frequent change of occupation. All examined were divided into two groups - those exposed to large amounts of dust (those employed at the face) and those exposed to relatively small amounts (those away from the face). In the order of exposure to the dust hazard the men at the face included shovelers' helpers, shovelers, drill helpers, machinemen, trackmen, roof trimmers, powdermen, shovel bosses, and ground bosses. According to analysis of the occupations of face workers the hazard was greater for shovelers' helpers and shovelers than for machinemen if length of time required to produce first-stage silicosis is a criterion. It is noted from table 12 that the average number of years worked by shovelers' helpers and shovelers was 6.8 and 8.4, respectively, while that for machinemen was 11.4.

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TABLE 12. - Period worked at face by first-stage silicotics

Job	Average years	Men	Job	Average years	Men
Shovelers' helpers (bruno men).	6.8	8	Machinemen (drillers)..	11.4	348
Shovelers	8.4	428	Powdermen....	11.5	24
Drillers' helpers (dummies)....	8.4	79	Shovel bosses	15.8	21
Trackmen.....	9.8	52	Ground bosses	19.0	54
Roof trimmers.....	11.3	26			

Loading and hauling. - Under some conditions hand loading of coal throws into the air of the working place considerable quantities of dust, but the amount is about one-tenth that caused by some types of mechanical loading. The greatly increased occurrence of dust from mechanical loading is due not only to the stirring of the dust into the air by the loading machines themselves but also to the greater rapidity of breaking down and taking coal from the face regions, which increases other dust-producing processes, especially blasting, cutting, and hauling (29).

Poorly constructed or poorly maintained pit cars or overtopping of coal in cars allow larger sizes of coal to fall off or fine material to sift through to the tracks to be ground under the wheels of rolling equipment or the hoofs of mules and then to be thrown into the air by speeding cars or shuffling mules or men (29).

Where conveyors (either the shaker or belt type) are used they form potential sources of dust clouds at the points where the coal is dropped or thrown, which occurs at the discharge ends only. Also, where conveyors are used conditions at the face differ from those experienced with the older methods of working in that the miners are closer together, there is a tendency with the more systematic working for a larger number of the men to perform dust-raising operations at the same time, and the air speed at the faces is higher (30). These conditions, if not controlled, tend to increase the dust exposure to the face workers.

Machine coal cutting. - When coal-cutting machines came into the picture early in the present century to supersede in large part both hand cutting and blasting off the solid, the really heavy producer of coal dust that the worker has had to endure was at hand, and this was especially true of the chain machines operated by electricity. Top-cutting is the worst offender in so far as impregnating the air with dust is concerned, shearing occupies an intermediate position, and undercutting is the least offensive in this respect. However, undercutting machines under some conditions (such as cutting dry in friable coal with dull bits in a confined place with little or no circulating air) may produce air dustiness so dense as to reduce visibility almost to zero with available types of mine lighting and to cause between 100,000,000 and 500,000,000 (or even more) dust particles to be carried per cubic foot of air of the face region (29).

Methods of Controlling Dust in Mining Operations

The principal measures for controlling dust in mining operations are ventilation, wet methods, proper blasting practice, the use of personal respiratory protection, and physical examination.

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Ventilation. - The more or less generally accepted conclusion that coal miners suffer less from miners' consumption than metal miners, who either die early in life or are incapacitated in middle age, is due almost entirely to the superior working conditions in coal mines as a result chiefly of ventilation.

Approximately in order of their importance, the main features that affect air in metal mines are (1) movement, (2) temperature, (3) relative humidity, (4) gases, and (5) dusts. In coal mines the order of importance would probably be (1) movement, (2) gases, (3) dusts, (4) relative humidity, and (5) temperature (31).

The matter of movement of air from the surface, through the working faces or places, and then back to the surface is by all means the most important consideration in effecting adequate ventilation of mines and in protecting the health and forwarding and maintaining the working efficiency of the underground workers. If adequate quantities of pure air are directed to the places where men work, most of the requirements of health and many of the demands of safety will be well-served (31).

Ventilation probably is the most effective dust-control measure, although under some conditions it ranks second to wet methods. Where ventilation can be applied effectively, dust can be removed from the air or its concentration can be so diluted as to render it almost harmless (29).

Wet Methods. - As dry drilling is the dustiest operation in mining, wet drilling will keep air dustiness within safe limits if used with care and judgment in collaring wet, using plenty of clean, dirt-free water, and keeping the drills in good repair with adequate regulation of the proportion of water and compressed air flowing through the drill steel (29).

In tests by the Bureau of Mines (32) the dust concentration in the air during actual drilling decreased as the water flow through the drill increased. The water flow for stopers was 0 to 3 gallons per minute and that for drifters from 0 to 1.02 gallons per minute. The rate of decrease for stoper drills was greater for water flows from 0 to 1.3 gallons per minute than for higher water flows. The rate of decrease for drifter drills was similar to that for stoper drills at corresponding water flows and rather constant for water flows of 0 to 1.02 gallons per minute.

The results of this study show that as water flow through the drills was increased the dust concentrations in the air decreased, but they do not show whether the decrease was caused directly by the increased water flow, by some condition influenced by variation in water flow, or by a combination of these factors.

In most pneumatic rock drills air passes through the drill steel with the water. Ordinarily some of the high-pressure air supplied to the drill for its operation escapes into the back end of the drill steel, even when the operating throttle is not in the blowing position and travels up to the face of the hole being drilled. The amount of air escaping is affected by

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the water flow through the drill steel; as the water flow through the drill steel increases the air flow decreases. Mining officials in South Africa concluded that such air leakage, although probably facilitating removal by the water of the cuttings from the hole, was responsible for entrapping fine dust and blowing it into the air during drilling (31). Consequently they have devoted much attention to designing drills that permit the minimum practical air leakage through the drill steel and have established regulations on the use of such drills. Canada is also doing much work along this line, and recent reports state that such drills are practical and produce about one-fourth the dust concentration of corresponding drills without the "dustless-head" features (31).

The results of this study show that operators can reduce dust concentrations resulting from drilling by increasing the water flow through the drill steel, either by increasing water pressure or by the use of water tubes of larger inside diameter.

Tests also have been conducted by the Bureau of Mines (32) on the effectiveness of spraying water along the outside of the drill steel compared with that of standard wet-drilling practice. The tests show that spraying water along the outside of the drill steel should not take the place of regular wet drilling underground. However, if a method is developed by which the device may be used on holes of any inclination, it might prove to be a valuable accessory to regular wet drilling in collaring and drilling the first 2 feet of a hole. Tests show that the greatest amount of dust is thrown into the air of a working place in drilling the first 2 feet of a hole (33).

Wet-drilling standards have been adopted in New York State for drilling in various classes of rock. The requirements for drilling in class II rock (rock containing more than 10 percent free silica) in confined areas, which include the use of mechanical ventilation, are quoted below (34).

> 1. Wet drilling shall mean the continuous application of water through the central hole in the hollow drill steel to the bottom of the drill hole. The central hole in the steel shall not be less than 3/16 inch in diameter.
>
> 2. The water flow shall be maintained continuously whenever the drill is in operation, including the period of collaring or starting the drill hole. The valve in the water line shall be of such design that it has only two fixed positions, namely, closed and completely open. Six months after date of approval, all wet drills shall be equipped with a combination air throttle and water valve of such design that the required rate of water flow through the drill steel will be insured whenever the air throttle is in the operating positions, half speed as well as full speed.
>
> 3. The water shall be clean and bacteria free and shall be delivered to the drills under pressure from an adequate source of supply. Portable water tanks for individual drills shall not be used unless approved by the Industrial Commissioner.

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Wet drilling in Class II rock in confined areas shall be used with mechanical ventilation or in confined areas under decking by natural ventilation if approved by the Industrial Commissioner and subject to the following provisions:

1. The rock surfaces for a distance of 30 feet from the heading or other drilling area shall be maintained in a damp condition.

2. Hand-held drills (maximum piston bore, 3 inches), minimum rate of water flow through drill steel 0.75 gallon per minute; maximum rate of air flow through drill steel at full speed 2.0 cubic feet per minute; maximum rate of air flow through the drill steel at half-speed operation 1.0 cubic foot per minute; minimum rate of general ventilation in the drilling area 500 cubic feet per minute per drill, and shall be increased if found upon tests by the Industrial Commissioner that the dust concentration is not in accordance with the requirements of the Code.

3. Drifter-mounted and wagon-mounted drills (maximum piston bore, 4 inches), minimum rate of general ventilation per drill in the drilling area as follows:

Class of drill			Limitations in air and water flow through steel				
			Full-speed operation		Half-speed operation		Minimum rate of ventilation for one drill, cu.ft. per min.
	Air flow	Water flow	Air, cfm	Water, gpm	Air, cfm	Water, gpm	
I	High	Low	4-6	0.5-0.75	5-12	0.5-0.75	2,500
II	Medium	Medium	2-4	0.75-1.5	2-5	0.75-1.5	2,000
III	Low	High	0-2	1.5 and over	0-2	1.5 and over	1,200

4. In the case of positive-pressure ventilation, the air must be well distributed over the drilling and must not create drafts at the various drilling positions in a manner satisfactory to the Industrial Commissioner. The intake for the ventilating system must be located at a point free free from contamination with dust or provided with an efficient filter.

5. In the case of exhaust ventilation, the location of the intake pipe or pipes must be such as to insure the removal of air from the entire drilling area in a manner satisfactory to the Industrial Commissioner.

6. The required ventilation may be obtained by means of a recirculating air-cleaning apparatus provided the dust concentration in the air at the breathing zone of the drill operators is maintained at a level below that required in Rule 33-2.3 and the apparatus is otherwise acceptable to the Industrial Commissioner.

7. The above rates of ventilation shall be increased whenever necessary to reduce dust concentration to the amount permitted by Rule 33-2.3.

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Proper blasting practice. - Methods of controlling dust and fumes in mines by proper blasting practice have been determined by members of the Bureau of Mines staff by observation and experiment (29,35). If at all feasible, blasting should be done at the end of the working shift or on an off shift, and the dust- and gas-laden air should be removed or thoroughly diluted before the men return to work. Ventilation is an essential agency in cleansing the air where blasting has been done. Results of investigations by the Bureau of Mines (36) show settling rate of dust after blasting under the following conditions:

1. The atmosphere was bratticed off for 3 hours while the dust samples were being taken. In this period, under these conditions, the dust concentration dropped from approximately 5,000 million particles per cubic foot to 50 million particles per cubic foot.

2. The atmosphere was bratticed off until 26 minutes after blasting, when the brattice was raised and natural ventilation (which was virtually negligible except for eddy currents) was allowed to dilute the dust-laden air. It required 2 hours and 20 minutes after blasting for the dust concentration to drop from approximately 5,000 million particles per cubic foot to 50 million particles per cubic foot, and 2 hours and 50 minutes to drop to 15 million particles per cubic foot.

3. The atmosphere was bratticed off until 37 minutes after blasting, when the brattice was raised and 10-inch canvas tubing installed to about 50 feet from the face. At 46 minutes after blasting, about 1,000 cubic feet of air per minute was forced into the face. It required 66 minutes after blasting for the dust concentration to drop to 50 million particles per cubic foot, and 70 minutes to drop to 15 million particles per cubic foot.

The following table shows the time, in minutes, required for the dust concentration to drop from 825 million particles per cubic foot to 50 million and to 15 million particles per cubic foot under the three different conditions:

Ventilating condition	Time, in minutes, to drop from 825,000,000 particles per cubic foot to -	
	50,000,000	15,000,000
No ventilation.....	121	181
Natural ventilation.....	105	135
Mechanical ventilation.....	20	24

In addition, the place (walls, floor, roof or top, and timbers) should be wetted thoroughly before blasting is done, and a water blast should be used during and after the blasting. The region should be wetted thoroughly when the men return to the face region after blasting, and the muck pile should be kept well wetted at all times while it is loaded out, as the water not only lays the dust but also either absorbs or otherwise aids in diluting or eliminating harmful or poisonous gases that follow blasting and that usually cling to the blasted material.

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Tests (35) on the effectiveness of a spray of water mist in reducing the concentration of dust in the air after blasting and during mucking of the blasted material were conducted in three headings in medium hard to hard rock. The use of the spray apparently made it possible to reduce the concentration of dust generated and thrown into the air during blasting more than 99 percent from the amount present when the spray was not used. Dust dissemination during mucking of material sprayed several hours before mucking was begun was much less than during shoveling of material thoroughly sprinkled just before and during mucking; and, of course, the dust present after use of either the spray or the sprinkling method is far less than if the mucking had been done dry.

In general, the larger the quantity of explosive used, the more finely divided the blasted material, the more heavily the air will be impregnated with dust and smoke, and the greater will be the quantity of poisonous gases left at the place; hence, methods should be used that will tend to reduce the quantity of explosives used and of gases and dust produced. In this connection it will be found that the use of stemming or of some types of blasting plugs now available will confine more definitely the explosive, hence, increase its efficiency and reduce the quantity of explosive used and also reduce the amount of poisonous gas produced and possibly reduce the violence of the blast and its tendency to raise dust and disseminate it into the surrounding air. It would be well for users of explosives to investigate types of explosives that are known to give off minimum quantities of harmful gases on detonation and to use them; also, the discontinuance of the use of fuse and the substitution of electric blasting would aid in reducing the amount of poisonous gases from blasting. Explosives that have been held in storage too long or that have been stored under unfavorable conditions as to moisture, temperature, etc., are likely to give off maximum quantities of harmful gases, if they detonate at all; hence, utmost care should be taken in the storing of explosives to see that they are not held too long before being used.

Personal respiratory protection. - This method of control of air dustiness is unsatisfactory in underground mining except for temporary use in emergencies. Although dust respirators give adequate protection against dust, they afford the wearer essentially no protection against toxic or asphyxiating gases, and are too cumbersome and uncomfortable for constant wear.

The Bureau of Mines has established a schedule of minimum requirements for mechanical-filter respirators, one type of which is for protection against dust generated by disintegration as in drilling and blasting. About 30 respirators have been approved under this schedule.

Physical examination. - Although strictly speaking physical examination is not a dust-control measure, it is an important means of determining the efficacy of the methods employed to reduce the dust hazard. If workers exposed to dust are examined periodically increased incidence of respiratory disease can be discovered and measures taken to reduce the amount of dust in the air or remove any affected workers to a less hazardous environment.

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In South Africa all white applicants for underground work are examined and certified to be physically fit and free of any disease of the respiratory organs and then re-examined every 6 months to determine and report all cases of simple silicosis, tuberculosis with silicosis, and simple tuberculosis that may have developed. In this way comparable records can be obtained for measuring the degree of pneumoconiosis and the extent of impairment of working capacity among employees from year to year. Comparable records will not be obtained unless periodic examinations are conducted in a standardized way, preferably by a permanent medical board composed of physicians specially trained and having adequate experience in the diagnosis of pulmonary diseases.

SUMMARY

1. The principal pulmonary diseases to which the miner is subject are bronchitis, influenza and pneumonia, pulmonary tuberculosis, anthracosilicosis, and silicosis.

2. Statistics indicate that much higher morbidity and death rates from pulmonary diseases are experienced in dusty than in nondusty industries, especially where silica dust is used or produced.

3. Investigations by the Public Health Service reveal that hard-coal miners suffer a high mortality rate from influenza and pneumonia not only during influenza epidemics but at other times as well. In 1915-23 and 1906-25 influenza and pneumonia were responsible for 40 percent of the total deaths among hard-coal miners, compared with 25 percent among males at ages 15 to 65 who were engaged in pursuits other than coal mining. Six percent of hard-coal miners had pulmonary tuberculosis, compared with 2 percent in the adult male population of the United States. The rate for metal miners is still higher.

4. Anthracosilicosis was found in about 23 percent of 2,711 employees of three anthracite-mining companies studied by the United States Public Health Service in 1933. About 63 percent of those having anthracosilicosis showed evidence of disability, compared with less than 10 percent in the control group. Moderate and marked degrees of disability handicapped approximately 21 percent of those with anthracosilicosis, compared with less than 2 percent of the men serving as controls.

5. The occupational groups in anthracite mining, arranged by the Public Health Service according to extent of physical impairment, are (1) rock workers, (2) regular miners, (3) all others exposed to more than 100 million dust particles per cubic foot of air, and (4) men in haulageways except rock workers.

6. The principal pulmonary disease in metal mines is silicosis, and the chief menace in silicosis is tubercle infection. Apparently silica dust alone increases the liability to pulmonary tuberculosis.

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Joint studies made by the Actuarial Society of America and the Association of Life Insurance Medical Directors (20) revealed that there were 65 deaths where 6 were expected (about 11 times the expected number) from tuberculosis in 1925–1936 among a group of underground miners, most of whom were employed in metal mines. Tuberculosis deaths were fourteen times the expected among copper miners, nine times the expected among gold and silver miners, and eight and a half times the expected among iron miners. In an earlier study (20) covering the years 1915–1926 there were 18 times as many deaths as expected among lead and zinc miners.

7. As dust is the greatest contributor to the excessive mortality from pulmonary diseases in the mining industry, the principal method of preventing these diseases is to eliminate as far as possible or reduce to harmless concentrations the dust in the breathing zone of the worker.

8. The aim should be to eliminate the dust entirely from the air breathed. Where this is not always feasible it may be possible to reduce the dust to a concentration that will not cause disability during a working lifetime.

9. Analysis of data collected by the Public Health Service to determine safe limits of dust exposure indicate that employment in an atmosphere containing less than 50 million dust particles per cubic foot produces a negligible number of cases of silicosis when the quartz content of the dust is less than 5 percent; when the silica content is about 13 percent 10 to 15 million particles appears to be a safe limit.

10. The amount of harmful dust created by various activities in mining can be determined by sampling the atmosphere in their vicinity and counting and identifying the dust particles. Sampling of air is also a means of checking the efficiency of dust-control measures.

11. The impinger is the dust-sampling instrument used most frequently in the United States.

12. The dustiest operations in mining are dry drilling, blasting of dry rock or ore, shoveling or mucking, loading and hauling, and machine coal cutting.

13. The principal measures for controlling the ill effects of dust in mining operations are ventilation, wet methods, proper blasting practice, the use of personal respiratory protection, and physical examination of workers.

14. The efficiency of these measures in the reduction of the incidence of dust diseases is attested by the experience in the mines of South Africa, where among the whole body of miners the liability to contract silicosis in 1936–37 was less by 65 percent than it was in 1920–23. Among the "new Rand miners" who entered the industry by way of initial examination since 1916 and who have been exposed solely to the progressively improving occupational conditions that have obtained since that date, the liability to

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contract silicosis was less by 87 percent than the similar liability among all miners working for an equal period in 1920-23. These "new Rand miners" constituted 77 percent of all working miners examined.

CONCLUSION

The mortality and morbidity from pulmonary diseases are excessive in the mining industry as a result of exposure to large amounts of dust in the air breathed. Therefore, control of the dust hazard is necessary to prevent these diseases. No single measure of control is applicable to all dusty operations and processes; therefore, all the means of prevention must be practiced to insure success in the solution of the problem.

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